SOME PSYCHOPHYSICAL PROPERTIES OF CATEGORY JUDGMENTS AND MAGNITUDE ESTIMATIONS

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Psychology in the Graduate School of Arts and Sciences of Duke University

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ABSTRACT

(Psychology-Experimental)

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There are several indications in the literature that the psychophysical methods of category judgment and magnitude estimation are very similar, even though they have traditionally been thought to give rise to different types of psychophysical scales. This paper presents a study of the two methods in a controlled experimental situation. The same stimuli (loudness levels) were presented to eight subjects for both category judgments and magnitude estimations. Everything in the situations was the same except the instructions about the method of judgment to be used on a particular occasion.

The resulting data were analyzed for several psychophysical properties. It was found that: (1) category judgment and magnitude estimation are extremely similar methods of psychophysical judgment in that they both exhibit time order error, central tendency of judgment, biases due to the effects of previous stimuli and responses, identical symmetry (defined in text) violations, and response variance discriminability and end effects,

(2) the data of both methods are adequately fit by a power function of the form $R = aS^N + b$, (3) the ratio between the exponents of the power functions fit to the data of the two methods seems to be constant at about 2:1 (magnitude estimations to category judgments) for six different prothetic perceptual continua, implying equal cross-modality validation of the two resultant psychophysical scales.

From the pattern of results summarized above it was concluded that: (1) the same fundamental judgment process, comparative category judgment of differences, seems to underlie both methods, and (2) although the data of both methods are well fit by a power function, the two scales can at best be considered interval scales.

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Lawrence M. Ward

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SOME PSYCHOPHYSICAL PROPERTIES OF CATEGORY JUDGMENTS AND MAGNITUDE ESTIMATIONS

INTRODUCTION

In psychophysical judgment tasks, a subject is typically asked to produce a response to a particular perceptual stimulus according to a rule provided by the experimenter. Responses are usually numbers, but adjectives have also been used. Recently several investigators have asked the subject to produce as the "response" a stimulus level on a perceptual continuum which is different from the stimulus continuum [this is called cross-modality matching, Stevens (1959)]. The responses produced by the subjects to the various stimulus values, in all of these methods, usually provide at least a monotonic ordering of the stimuli according to some physical dimension along which they vary. A common object of the studies in this area is to produce a psychophysical scale of the perceptual dimension which indicates the relation of the physical measure of the stimulus dimension to a measure of the sensation "caused" by the stimulus (such as loudness of sound, brightness of light, etc.).

Several investigators conceive of psychophysical judgment as a matching task. Attneave (1964), Ekman (1964), and Stevens (1966) have all suggested that Stevens' magnitude estimation task may be viewed as a cross-modality

matching task in which stimulus sensation is matched to "number sensation" to produce the response. Ward and Lockhead (1970b) have proposed that the classical category judgment task is a task in which a stimulus sensation is matched to a remembered response scale.

Stevens (1966) believes all judgment to be a form of matching. In psychophysical judgment, a particular stimulus range is matched by the subject to a particular response domain (e.g., the numbers 1-10) according to a particular rule. If the subject follows the instructed rule of matching, then different rules of matching give rise to different types of psychophysical scales (Stevens, 1951).

The method of magnitude estimation is supposed to produce a ratio scale. This is because the subject is instructed to assign a number to a stimulus by considering the ratio between that stimulus and another, already numbered, stimulus. The scale has a true zero, and is unique up to multiplication by a constant. A great many experimenters have found that, for stimulus dimensions of a class called prothetic (Stevens and Galanter, 1957), responses produced by the method of magnitude estimation generally are a power function of the stimulus magnitude measured in physical units. Stevens prefers to express this relation as $R = a(S-S_o)^N$, retaining the idea of a ratio scale, where R is the response, S is the stimulus magnitude, S_o is a stimulus scale translation to correct for distortions near threshold, a is a constant representing the unit of the scale, and N is the exponent of the power function.

Another type of judgment that has received a great deal of investigation is the method of category judgments (or single stimuli, or absolute judgments) introduced by Wever and Zener (1928). This type of judgment is supposed to result in only an interval scale (with no true zero point) since the subject is instructed to consider intervals or differences on the stimulus scale, rather than ratios. For prothetic continua, the category scale is neither logarithmic with the stimulus magnitudes (Fechner's Law) nor linear with the magnitude estimation scale (Stevens and Galanter, 1957). It is always concave downwards when plotted against the magnitude estimation scale. Because of the nonlinear relation of the two scales, and because the category scale is no more than an interval scale while the magnitude scale was thought to be a ratio scale, Stevens (1966) expressed the opinion that the category scale should not be used to investigate the operating characteristics of sensory systems.

The above two methods are probably the most used and the most controversial of the psychophysical methods. They are similar in that they both involve matching a stimulus range to a response domain by a particular rule. However, the particular rule by which subjects match stimuli to responses in category judgment may force them to ignore ratios, ". . . for only by accident will the top and bottom stimuli stand in the relation of [the highest available response to the lowest]. Either implicitly or explicitly, we ask the matcher to divide the segment of the perceived continuum into [several] equal parts and to assign [several] numbers in a manner that

reflects the equal partitions" (Stevens, 1966, pp. 393-394). According to this idea, category judgment is then subject to a distortion introduced by the fact that discrimination becomes poorer as the magnitude of the stimuli being discriminated increases (Weber's Law). In other words, since the subject cannot discriminate between the stimuli at the top of the range as well as he can between those at the bottom, he puts more of the top stimuli into a single category. This would make the stimulus-response relation steep at the bottom and shallower at the top of the stimulus range. Stevens (1966) assumes that this bias does not affect magnitude estimations since the subjects are presumably considering the ratios between stimuli, rather than putting them in categories. Thus the nonlinearity of category judgments with magnitude estimations results from the category judgment's susceptibility to this source of bias.

There is some evidence that the situation is not this simple. First, with respect to the form of the power law, Fagot and Stewart (1968) report a detailed study of magnitude estimations of brightness in which they compare two forms of the power law. They conclude that the form assumed by Stevens and many of his associates, $R = a(S-S_o)^N$, is inferior to the form suggested by McGill (1960) and others, $R = a(S)^N + b$. The first of the two forms implies that distortions near threshold are corrected by a translation of the stimulus scale (luminance in the case of the Fagot and Stewart study) by a constant (S_o) amount. The second implies that these distortions are corrected by a translation of the response scale (brightness) by a constant

(b) amount. The first of these scales is a ratio scale, the second is an interval scale. The data of Fagot and Stewart (1968) clearly imply that magnitude estimation produces only an interval scale, and not a ratio scale as Stevens has assumed from the instructions to the subject.

Also, from a closer examination of the ways in which the subjects used responses, Fagot and Stewart (1968) found that the subjects whose data were poorly fit by a power function tended to make "category judgments" instead of magnitude estimations in the first few days of running. The subjects then seemed to change from this method of judgment over the last few days of running. Thus their data were inconsistently produced. Fagot and Stewart (1968) argue that this means that two factors were confounded in their test of the psychophysical law: the form of the psychophysical law, and the validity of the magnitude estimation scale.

Second, there is some evidence that the exponent of the power function fitted to magnitude estimation data may be influenced by the Weber's Law bias. Poulton (1968) reviews a large number of studies of the method of magnitude estimation and finds that the range over which the stimuli vary in a particular experiment is negatively correlated with the size of the exponent of the power function that is fitted to the data. In other words, the larger the stimulus range used in the experiment, the smaller the exponent obtained. He states that this one factor accounts for about 33% of the variance between the exponents reported by different experimenters for the same perceptual continuum. In addition, Gravetter and Lockhead (1970) report that the range

over which the stimuli vary in a category judgment experiment affects the discriminability of the stimuli. They extended the range in an absolute judgment of loudnesses experiment, with feedback, by moving the stimuli at the ends of the stimulus ensemble away from the midpoint of the series. The middle stimuli in the series were left unchanged. Performance on those middle stimuli was poorer in the condition with the end stimuli moved out than it was in the condition in which the stimuli were equally spaced. A decrease in discriminability of this sort, where a number of stimuli that were previously assigned different numbers are now put into the same category, implies a shallower slope of the psychophysical function for those stimuli. This effect could contribute to an increase in the curvilinearity of the psychophysical function with an increase in stimulus range.

If the range over which the stimuli vary in a particular experiment affects the discriminability of the stimuli, and the range also affects the exponents of power functions fitted to magnitude estimation data, then it may be that the method of magnitude estimation is subject to the variability of discrimination with stimulus magnitude in just the way that category judgments are. This would mean that subjects in these studies may be attending to intervals and not ratios, and producing an interval scale for magnitude estimation.

There is evidence that the two methods of judgment are subject to many other similar kinds of bias. Poulton (1968) found five major variables (besides stimulus range) that affect the exponent of a power function

fitted to magnitude estimation data. They are: (1) the distance of the stimuli from the "absolute" threshold, (2) the position of the standard in the stimulus ensemble, (3) the distance of the first variable from the standard, (4) whether the subject has available a finite or an infinite set of numbers with which to respond, and (5) the size of the modulus (the number that is assigned to the standard in this type of experiment). Situational variables known to affect responses in the method of category judgment are: (1) the range and probability distribution of the stimuli (Parducci, 1965), (2) interpolated anchor stimuli (Helson, 1959; Parducci and Marshall, 1962; Sherif, Taub, and Hovland, 1958), (3) the position of the standard in the stimulus ensemble (Helson, 1959), and (4) the spacing of the stimuli (Stevens, 1956; Stevens and Galanter, 1957). Also, Holland and Lockhead (1968) and Ward and Lockhead (1970a, 1970b) have shown that absolute judgments in the presence of an identification function are assimilated to the value of the immediately previous stimulus and response, and are assimilated to or contrasted with those stimuli and responses further back in the sequence, depending on the presence or absence of information feedback.

It is evident that the two methods are very similar in nature. In fact, Stevens (1956) reported that "some" subjects made interval judgments even when they were instructed to make magnitude estimations. And almost every subject protested loudly when first asked to make judgments of "ratios" between stimuli. Further, there is evidence that a power function will fit category judgments at least as well as it fits magnitude estimations

(Curtis, 1970). These data again raise the question of whether subjects are producing a ratio scale when using the method of magnitude estimation, or producing only an interval scale in much the same way as when doing category judgments.

For the present study, I am concerned with investigating the psychological processes involved in magnitude estimations and category judgments. Since the two methods seem very similar, an attempt to ascertain the exact degree of similarity between them in a controlled experimental situation might give insight into the processes involved in both kinds of judgment. The present concern is not with investigating the form of the psychophysical function in the sense of Fagot and Stewart (1968).

Subjects judged loudness levels by the method of category judgments (without an identification function from stimuli to responses) and by an analogous method of magnitude estimation. An attempt was made to have the two experimental situations identical in all respects except for those pertaining to the rule by which responses were made to the various stimuli. The resulting data were analyzed for several psychophysical properties. The data were also analyzed for sequential effects, since Ward and Lockhead (1970a) state that the presence of an identification function may be crucial for sequential effects such as they had observed. Such an analysis has never before been performed on magnitude estimation data, nor have previous studies analyzed changes in response strategies over a great many magnitude estimation trials.

METHOD

Subjects. Eight undergraduate volunteers, naive to psychophysical judgment, served as paid subjects for the study. Each ran in both experimental conditions. All had no known hearing defects and all performed adequately on the experimental tasks.

Apparatus and stimuli. The stimuli were 500-msec. duration, 1000-Hz. sinusoids generated by an oscillator (Hewlett-Packard 200-CD). A tape reader selected one of ten different attenuators on each trial, and the resulting amplitude was delivered diotically through high-quality headphones (Koss Pro-4A). Subjects sat in an IAC sound attenuation chamber during the experiment; ambient noise inside the chamber was very low. The same loudness levels were used in both experiments. The ten amplitudes delivered to the phones were: .310 mv., .615 mv., 1.19 mv., 2.35 mv., 4.60 mv., 9.10 mv., 17.9 mv., 35.0 mv., 69.0 mv., and 136.0 mv. These values were measured on a vacuum tube voltmeter, with an accuracy of 1% of the reading, placed in parallel to the headphones. The voltmeter introduced a 600 ohm resistance in parallel to the headphones; after measurements were made, a 600 ohm resistor was substituted for the voltmeter.

The attenuators were reset each day to assure that the voltages were always the same. The stimuli were chosen to be equally spaced on a log scale and adjacent pairs were 6 db. apart. The total stimulus range was thus 54 db., with the softest stimulus about 30 db. re. .0002 dynes/cm^2. The stimuli were gated by a timer-activated electronic switch to minimize transients.

Design. Each of eight subjects produced 500 responses (50 per stimulus) under each of the two judgmental conditions. Each subject judged the stimuli by the method of category judgments in one session which lasted about one hour. On a subsequent day, each judged the same stimuli by the method of magnitude estimations. The conditions were run in this order so that the category judgment situation would not be contaminated by training in a task requiring attention to previous stimuli. This possible source of bias will be discussed along with its remedy in the Results section. Also, for all subjects, an additional session, during which category judgments were made of the difference between pairs of the same stimuli, intervened between the two days of interest here. This condition was run for another reason and the data are not analyzed here. This too could have biased the magnitude estimations, and reason to believe that it did not will be presented later.

There was one random order of the 500 stimuli which could be presented either forwards or backwards. Each subject received the stimuli in one order for category judgments and in the reverse order for magnitude estimations. Four subjects started with the forward order in the category

judgment situation and four started with the backward order.

Category judgment. The subject was shown the equipment and briefly told how it worked and then was taken into the IAC chamber. He was told that he was going to make category judgments of loudness levels but was not told the number of different stimuli he would hear.

The subject was told to divide the range between the loudest stimulus and the softest one (which would be presented by the experimenter immediately before the task started) into ten equal intervals, or categories, numbered 1-10 for the softest to the loudest. He was to respond to each self-presented tone thereafter, one at a time, with a number which represented the category into which he thought it fell. Each response was to be written down immediately on the prepared answer sheet. He was told that if he thought he recognized a particular stimulus as one that he had heard before, he was not to try to remember or figure out what he had called it earlier, but to respond to it as it sounded on the present trial. (This instruction was common to both experimental conditions.)

It was explicitly stated that there was no correct answer for any given stimulus presentation, but rather that the subject was to make the judgment according to his own impression of the loudness of the stimulus. No practice trials were given since previous research (e.g., Wever and Zener, 1928) indicated that the judgments stabilized after the first few trials. There was no formal time pressure on the subject in the self-paced task, except that a timer required him to wait at least 1 sec. after a

particular tone ended before depressing the footswitch would present the next one. The subject was urged not to spend too much time on any one judgment and the average subject spent 3-5 sec. per trial.

Magnitude estimation. Each subject gave magnitude estimations to the same set of stimuli 2-8 days following the category judgments. They were not told that the stimuli were the same, although they may have known it since it has been shown that subjects remember stimuli judged earlier (Ward and Lockhead, 1970a).

It was decided to have the subjects do a magnitude estimation task which was more analogous to the category judgment task than the task typically used. Typically, on each trial, the subject is presented with two stimuli, a standard, numbered stimulus, and a variable unnumbered stimulus. The task of the subject is to assign a number to the variable in such a way that the ratio of his response to the number (modulus) of the standard reflects what he believes to be the ratio between the variable and the standard stimuli. This technique is analogous to the classical technique of comparative category judgment. However, since most category scales compared to magnitude scales have been of the absolute judgment variety, with no standard stimulus present on each trial, it was thought better to use a magnitude estimation technique more analogous to this task. Thus, the subject was asked to judge the ratio between the present and previous stimulus in the stimulus series, and to assign a number to the present stimulus so that the ratio of the present response to the previous response would

reflect what he believed to be the ratio between the present and previous stimuli. For the very first stimulus, the experimenter presented a particular stimulus and gave it a particular number (modulus). Thus, in essence this was a task with a variable standard, where the standard on each trial was the stimulus that had been judged on the immediately previous trial. More specifically, the equation $R(N) = R(N-1) \cdot S(N)/S(N-1)$, where $R(N)$ is the response on Trial N, and $S(N)$ is the stimulus on that trial, describes the task of the subject. Other experimenters have had success with this method (Curtis, 1970; Curtis, Attneave, and Harrington, 1968; Curtis and Fox, 1969).

Before starting the loudness judgment task, the subject judged line lengths in the same way that he would be judging loudnesses. This procedure has been recommended to minimize biases associated with the way subjects use numbers (Stevens, 1966). The range of line lengths was from 1-30 in. It was emphasized that there was no restriction on the numbers that the subject could assign to stimuli except his own ratio judgments. Stimuli (line lengths) were presented that led the subject to use very large numbers (in the hundreds) and very small numbers (close to zero). It was shown that there are a great many numbers between zero and one and that they were all usable if necessary (except for the 0). All subjects learned the task within a few trials.

After the experimenter was satisfied that the subject understood his task, he told the subject that the first loudness stimulus would be presented

by the experimenter and that it was to be called "10." Subjects were told not to take any excessively long (more than a few seconds) breaks during the session, as the accuracy of their ratio judgments depended on the accuracy of their memory of the previous stimulus. Subjects worked at their own rate, about 5-7 sec. per trial.

RESULTS

Psychophysical functions. The psychophysical function of each subject, and the function of the pooled data of the eight subjects, are plotted in log-log coordinates in Figure 1 for the category judgment experiment and in Figure 2 for the magnitude estimation experiment. In Figure 1 the logarithms of the arithmetic mean responses are plotted against the logarithms of the stimulus magnitudes in millivolts (voltage is a pressure measure for loudness). In Figure 2, however, the logarithms of the geometric mean responses are plotted, since the distributions of responses to the various stimuli in the magnitude estimation experiment were highly skewed.

The psychophysical functions are strikingly close to straight lines in these log-log plots for both experiments. However, it is obvious that the functions for category judgment are much less variable than those for magnitude estimation. There do seem to be systematic departures from a straight line in both experiments.

The fact that the functions are nearly straight lines in log-log coordinates means that a power function would provide a relatively good fit to the data, with the exponent of the power function being the slope of the best

Fig. 1. Psychophysical Functions for Eight Subjects and Pooled Data from Category Judgments of Loudnesses. The abcissa is the logarithm of the arithmetic mean response; the ordinate is the logarithm of the stimulus value in millivolts. For the functions of the individual subjects there are 50 observations per point; for the pooled function there are 400 observations per point. Information transmission averaged 1.18 bits.

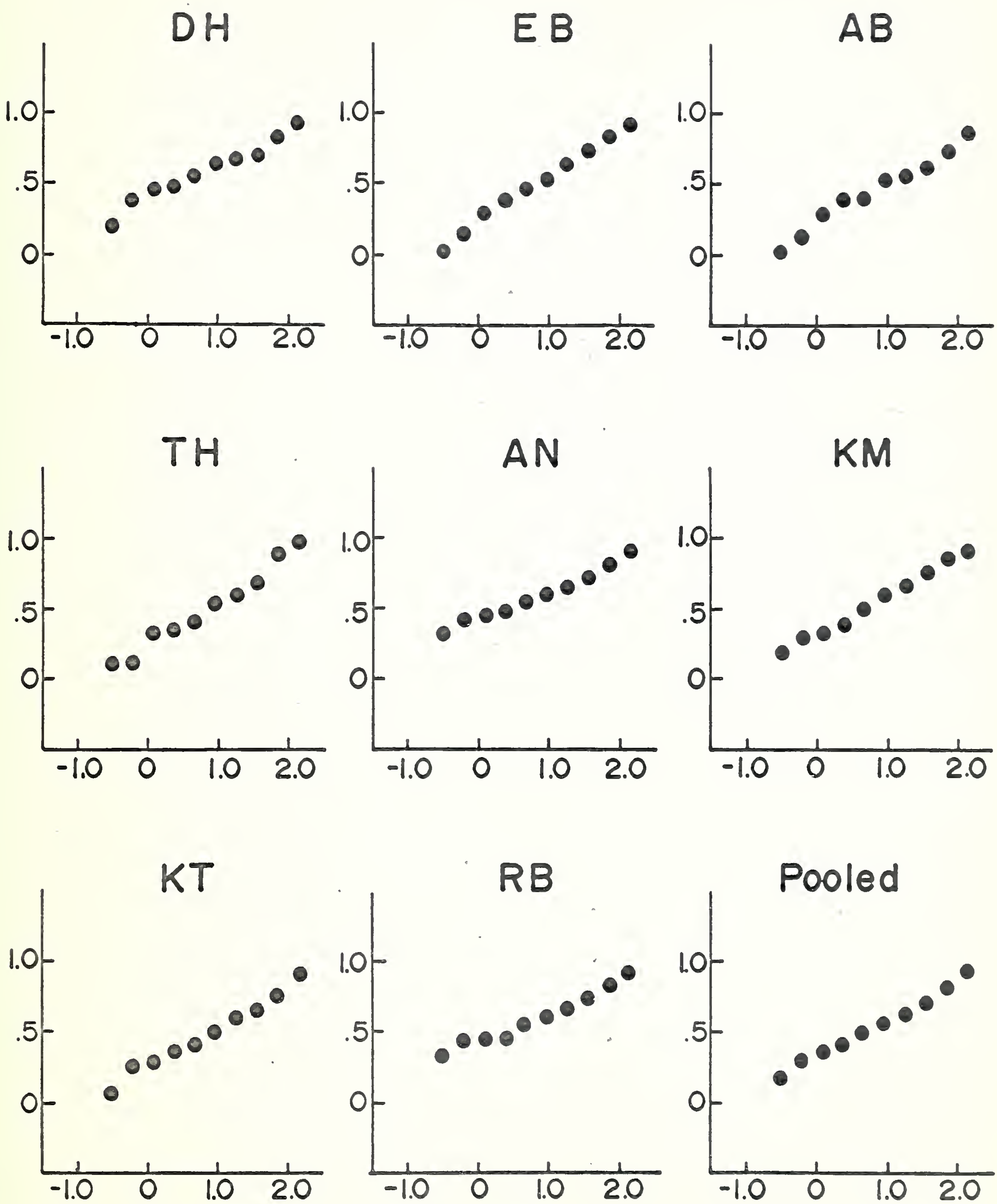
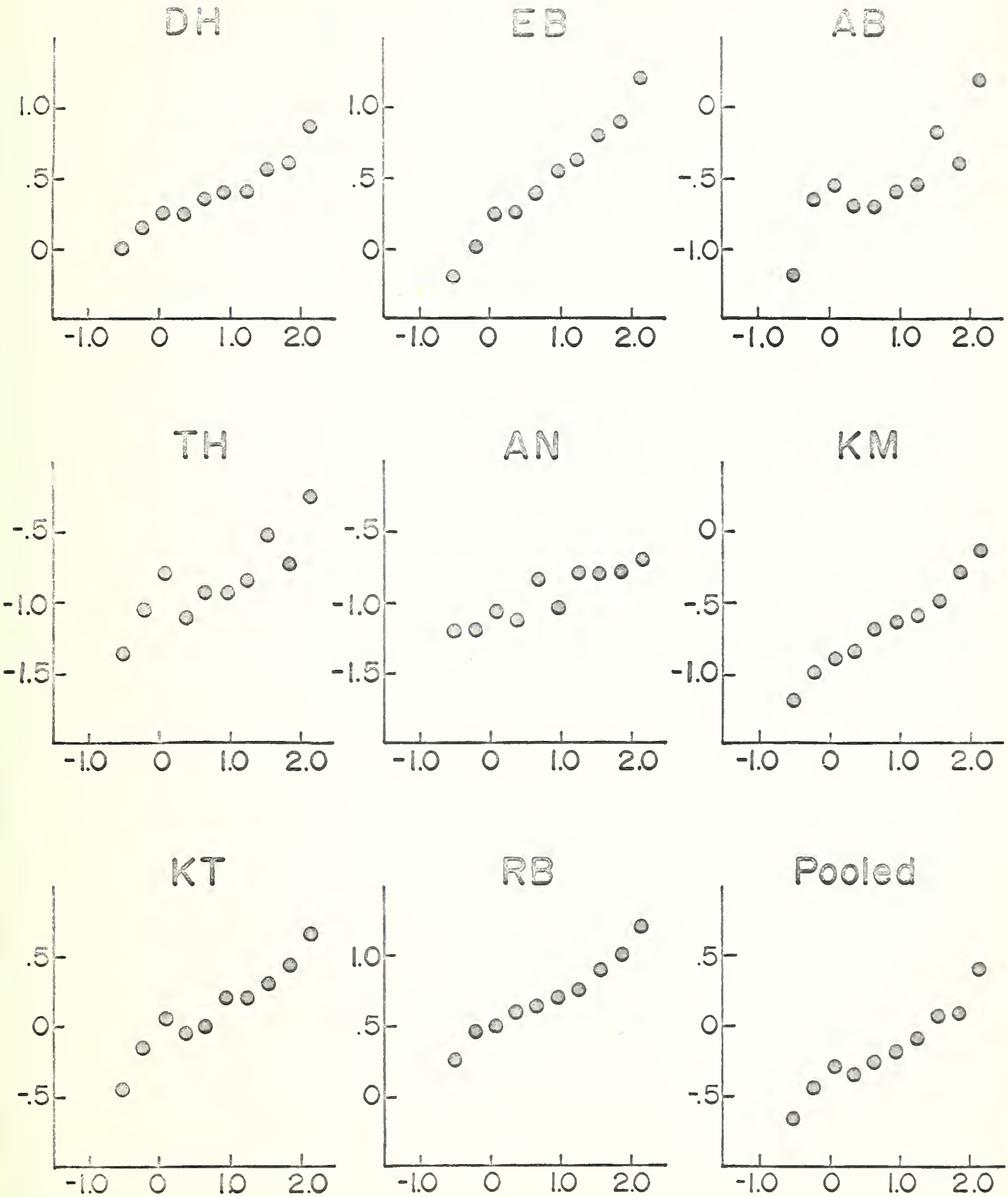

DH
EB
AB
TH
AN
KM
KT
RB
Pooled
1.0
.5
0
-1.0
0
1.0
2.0

Fig. 2. Psychophysical Functions for Eight Subjects and Pooled Data from Magnitude Estimations of Loudnesses. The abcissa is the logarithm of the geometric mean response; the ordinate is the logarithm of the stimulus value in millivolts. For the functions of the individual subjects there are 50 observations per point; for the pooled function there are 400 observations per point.


DH
EB
AB
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KT
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1.0
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-.5
-1.0
-1.5
-1.0
0
1.0
2.0

fitting straight line. Even though there are systematic departures from a power function observable in the data, a power function of the form $R = aS^N + b$ was fitted to the data for each subject, and for the pooled data, by the method of least squares (see Appendix). This particular form was chosen because the study of Fagot and Stewart (1968) indicated that it provided the best fit for their data, and because this form has been fitted to other data (Curtis, 1970; Curtis et al., 1968) collected by the methods employed in this study. There are three degrees of freedom in this equation (a, N, and b) and a good fit is to be expected. For most subjects this was attained, as can be seen by the standard errors of the exponents in Table 1. This table shows the values of the parameter N, which is the parameter of interest here, for each subject and the pooled data of each experiment. The values of N for subjects AB and TH in the magnitude estimation experiment are estimated roughly from the log-log plots, since the computer program used to fit the equation to the data went into a divergent iterative sequence on these data. The data for these subjects do not seem to be power functions. The exponent N reported in Table 1 may not seem equal to the slopes in Figures 1 and 2 in some cases; this is because of the extra degree of freedom in the fitted nonlinear equation.

Although the power function seems adequate to describe most of the data of both experiments, it can be seen in Table 1 that the average exponents differ for the two experiments. The exponent for the pooled data of the magnitude estimation experiment is almost exactly twice that of the

Table 1

Exponents (N) of Power Functions of the Form $R = aS^N + b$, Fitted by the Method of Least Squares to the Data of the Two Experiments

Subject	Magnitude Estimation		Category Judgment	
	N	Standard Error	N	Standard Error
DH	.790	$\pm$.145	.345	$\pm$.078
EB	.908	$\pm$.136	.308	$\pm$.020
AB	(.800)	--	.358	$\pm$.062
TH	(.700)	--	.490	$\pm$.068
AN	.121	$\pm$.202	.396	$\pm$.034
KM	.568	$\pm$.066	.366	$\pm$.027
KT	.687	$\pm$.125	.472	$\pm$.053
RB	.628	$\pm$.080	.384	$\pm$.034
Pooled	.781	$\pm$.157	.390	$\pm$.030

Note.--The pooled magnitude estimation scale was $R = .041(S)^{.781} + .378$; the pooled category scale was $R = 1.051(S)^{.390} + 1.047$.

same data in the category judgment experiment (.781 vs. .390). If a suitable admissable transform of the average category scale were plotted against the average magnitude scale, the resulting curve would be concave downward in linear coordinates, or a straight line with a slope of .5 in log-log coordinates. This is in line with the results of some experiments comparing the two methods (e.g., Stevens and Galanter, 1957), but somewhat different from others (e.g., Galanter and Messick, 1961).

The average exponent for magnitude estimation is a little higher than the typical exponent of .6 (for binaural stimuli measured in pressure units) reported by Stevens. That exponent (.6) is the average of a great number of experiments in a standardized situation that differs from the present one in several ways. The value of .6 does lie well within two standard errors of the exponent of $.781 \pm .157$ estimated from the pooled magnitude estimation data.

Time order error. Any systematic deviation from a perfect match of the center of the stimulus range to the center of the response domain has classically been called time order error. The data from both experiments were analyzed for this property of classical psychophysical judgment.

If the stimuli are numbered from 1-10, for the softest to the loudest stimulus, then the average stimulus presented in both experiments was 5.5 since each stimulus occurred an equal number of times. In the category judgment situation, the mean of the 4000 responses of the 8 subjects was 3.91, 1.59 category units below the value of the average stimulus. This

represents a sizable negative time order error and each subject displayed the effect to about the same extent.

For the magnitude estimation data, stimulus number 5 was always the first stimulus presented and it was always labeled "10" at that time. The number "10" is said to be the "modulus" in an experiment of this type. The response to this stimulus should continue to be "10" whenever it occurs (except for random error) if the modulus does not change over time. Experimenters do not generally report whether the modulus changed in magnitude estimation studies, and most experimental situations are designed to minimize effects of this sort. One typical way of doing this is to present a standard, whose label is always the modulus, on every other trial so that the variable stimulus is always compared with it. This would assure that the modulus remained constant.

In the present experiment, however, no attempt of this sort was made. The theoretical "standard" stimulus (number 5; 4.60 mv.) occurred at random in the sequence of stimuli. If a tendency toward a time order error was operating in this situation, it should manifest itself by a systematic change over trials in the response to stimulus number 5. Table 2 shows the logarithm of the geometric mean modulus, by blocks of 100 trials, for each subject and for the average of the subjects. (Most of the data in this paper are presented in the form of logarithms since it is easier to work with geometric means in this form.) It can be seen that, for every subject, the modulus grew smaller (in all cases it started at log 10 = 1.0)

Table 2

Logarithm of Geometric Mean Modulus in the Magnitude Estimation Experiment by Blocks of 100 Trials

Subject	Trial Block				
	1	2	3	4	5
DH	.40	.30	.35	.28	.26
EB	.49	.47	.38	.38	.34
AB	.15	-.20	-.38	-.95	-1.73
TH	.15	-.45	-1.25	-1.50	-1.42
AN	-.25	-1.40	-1.41	-1.30	-.64
KM	-.50	-.70	-.80	-.92	-.85
KT	.10	.10	-.05	.10	.02
RB	.67	.58	.66	.67	.70
Average	.15	-.16	-.31	-.40	-.42

Note.--The numbers shown are the response scale coordinates of stimulus number 5. They were estimated from the best-fitting straight line through all the points on a log-log plot (for the particular trial block) of the geometric mean responses against the stimulus values in mv.

over the course of the 500 magnitude estimations. The numbers in the fifth block of trials do not represent the final moduli, since they are averages over the last 100 trials.

It can be seen that there was a great deal of variability in the rate and in the magnitude of the modulus change. Some subjects changed by less than 1 order of magnitude, while others changed by almost 3. In all subjects there was a tendency for the modulus to change a great deal in the first few hundred trials and then to level off. All subjects said that they noticed the change in modulus and were actively trying to compensate for it. At any rate, the overall effect was in the direction of a negative time order error.

The potential effect of this source of error is much greater in this method than in the method of category judgments since there is no limit to the numbers that can be used to describe the stimuli so long as the rule is followed. The meaning of this will be discussed more fully later in the paper.

Central tendency. The central tendency of judgment was discovered and named by Hollingworth (Guilford, 1962) for category judgments. It was found that, in general, stimuli toward the bottom of a stimulus range (in the direction of the absolute threshold) were overestimated, and stimuli toward the top of the range were underestimated. This has since become a common finding in experiments of this sort, and various explanations have been offered (Guilford, 1962; Johnson and Mullally, 1969; Ward and Lockhead, 1970b).

Although partially obscured by the rather large time order error, the data from the category judgment experiment show the expected central tendency. Referring to Figure 1, page 18, the central tendency shows best in the fact that the average response to stimulus 1 was greater than 1 (0 on the log scale) and the average response to stimulus 10 was less than 10. Also, a slight sinusoidal bowing of the functions can be seen, indicating that the responses to the lower stimuli would lie above, and those to the higher stimuli would lie below, a straight line through the end points. In all cases the average response to at least the softest stimulus, and in several cases a few louder stimuli, is greater than the value of the stimulus on an arbitrary 1-10 stimulus scale. All other stimuli are underestimated, with the degree of underestimation generally increasing with the stimulus magnitude.

This analysis is not appropriate for the method of magnitude estimation, since that method is not intended to be subject to the kind of stimulus-response pairing used in category judgment. However, it can be observed in Figure 2, page 20, that seven of eight subjects display a distinctly sinusoidal psychophysical function. If we were to draw a straight line connecting the end points of these functions, stimuli below the middle stimulus would fall above the line, and stimuli above the middle would fall below it. In other words, with respect to this hypothetical line at least, low stimuli were overestimated and high stimuli were underestimated. This is evidence for a central tendency effect in magnitude estimations.

Sequential effects. Figures 3 (category judgments) and 4 (magnitude estimations) show the average response to the stimulus on Trial N as a function of the stimulus on Trial N-1. The data are collapsed across subjects and pairs of adjacent stimuli in both figures. There are approximately 160 observations per point. The data of each subject in the category judgment experiment and 7 of 8 subjects in the magnitude estimation experiment are identical in form to the average data in the two figures, although of course more variable.

It is apparent that the two figures are practically indistinguishable; for the most part, the higher the value of the stimulus on Trial N-1, the higher the response to the stimulus on Trial N. This is not strictly true for stimulus 9, 10, since the point 9, 10 - 7, 8 seems to be displaced downwards. These data imply that the response to the stimulus on Trial N is assimilated toward the value of the stimulus on Trial N-1. This replicates the findings of Holland and Lockhead (1968) and Ward and Lockhead (1970a, 1970b) for category judgments with the extension that there was no identification function from stimuli to responses in the present experiment. The finding is now extended to the magnitude estimation situation.

Table 3 shows responses on Trial N as a function of the stimulus on Trial N-1 in a different way from Figure 3, and extends the analysis of sequential effects to stimuli as far as six trials back in the stimulus sequence. Each entry is the average of all subjects' responses to all stimuli on Trial N when the stimulus on Trial N-K was a particular value. There

Fig. 3. Average Response to the Stimulus on Trial N as a Function of the Stimulus on Trial N-1 for the Data of the Category Judgment Experiment. The data are the average responses of eight subjects, giving approximately 160 observations per point.

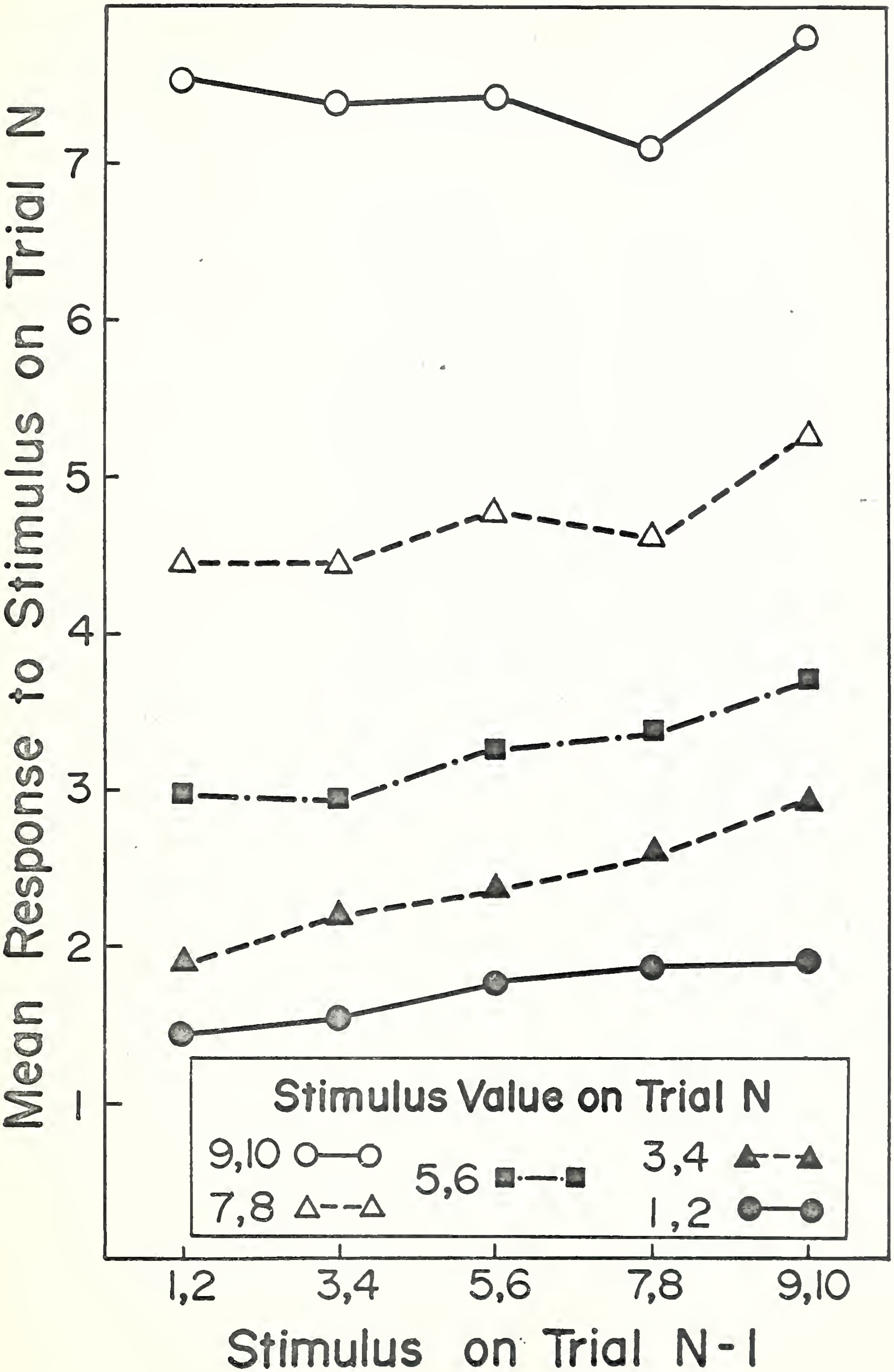

Mean Response to Stimulus on Trial N
7
6
5
4
3
2
1
Stimulus Value on Trial N
9,10
7,8
5,6
3,4
1,2
1,2
3,4
5,6
7,8
9,10
Stimulus on Trial N-1

Fig. 4. Average Response to the Stimulus on Trial N as a Function of the Stimulus on Trial N-1 for the Data of the Magnitude Estimation Experiment. The data are the average responses of eight subjects, giving approximately 160 observations per point.

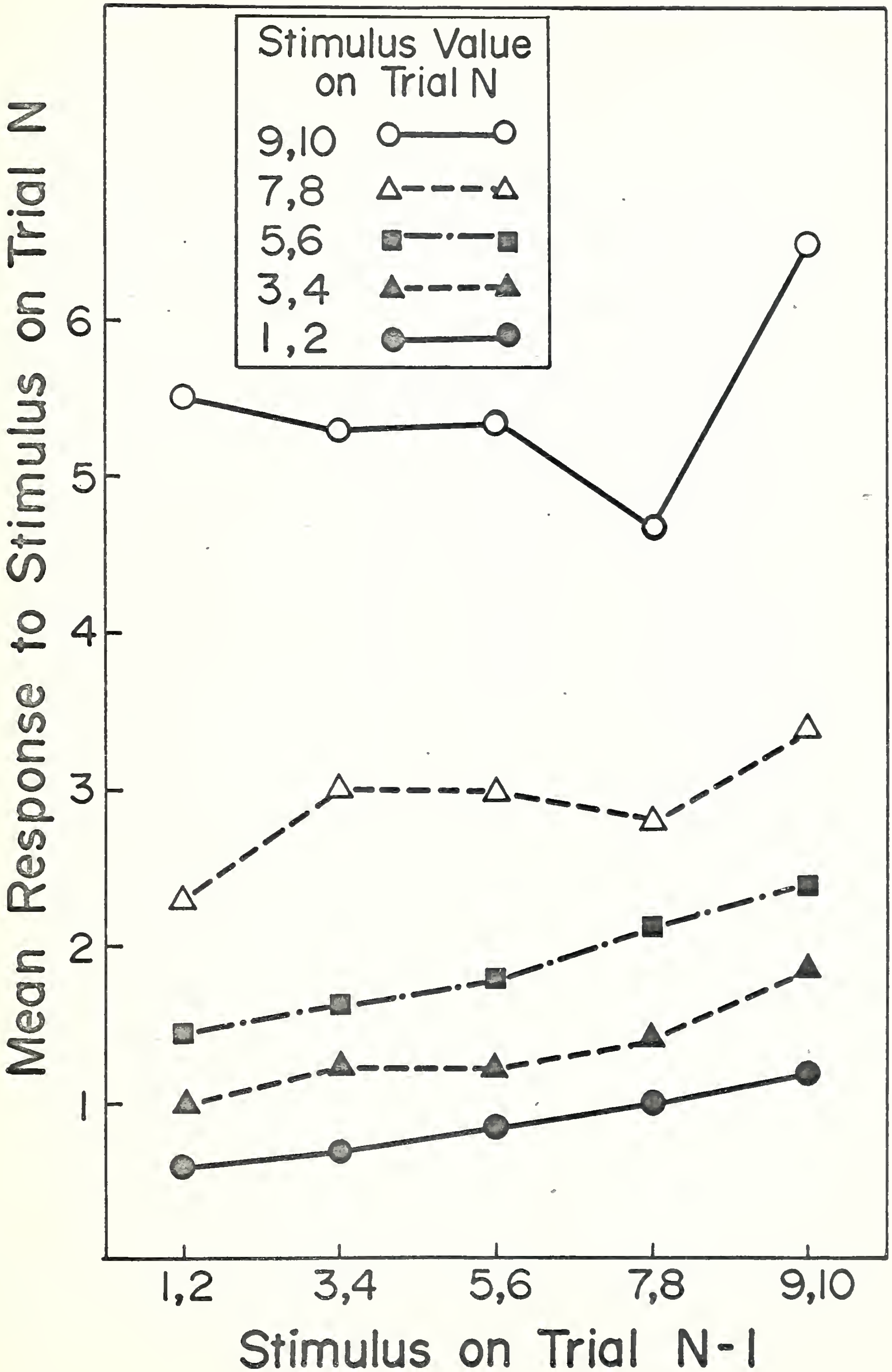

Stimulus Value on Trial N
9,10
7,8
5,6
3,4
1,2
Mean Response to Stimulus on Trial N
1
2
3
4
5
6
1,2
3,4
5,6
7,8
9,10
Stimulus on Trial N-1

Table 3

Average Responses in the Category Judgment Experiment as a Function of the Stimulus on Trial N-K (K = 1, 6)

Stimulus on Trial N-K	Average Response on Trial N					
	K = 1	K = 2	K = 3	K = 4	K = 5	K = 6
1	3.67	3.80	3.87	3.84	3.99	4.07
2	3.67	3.93	3.96	4.04	3.90	3.92
3	3.71	3.89	4.01	4.03	3.98	3.97
4	3.69	3.76	3.63	3.92	3.95	3.93
5	3.78	3.85	3.99	3.82	3.95	3.90
6	4.07	4.00	3.94	3.96	3.58	3.49
7	3.90	3.94	3.75	3.90	3.86	3.89
8	3.93	3.88	3.81	3.78	3.82	3.83
9	4.21	3.95	3.81	3.86	3.62	3.83
10	4.44	4.09	3.84	3.77	3.81	3.63
$r' =$	.898	.622	-.307	-.592	-.653	-.642

Note.--Also shown are the rank-order correlation coefficients between the average responses on Trial N and the stimulus value on Trial N-K. There are 9 degrees of freedom for each r'.

are about 400 responses per entry at each K-level. Rank-order correlation coefficients of the stimulus value on Trial N-K with the average response over all stimuli on Trial N are shown to indicate the direction and reliability of the effects. The magnitude of the correlation coefficient only indicates how reliable the ordering of the stimuli and responses is, not the magnitude of the effect itself. The latter can be seen by inspecting the difference between the average response when the stimulus on Trial N-K was small, compared with the average response when that stimulus was large. A positive correlation indicates assimilation of the response on Trial N to the stimulus on Trial N-K, a negative correlation indicates contrast. Inspection of the correlations in Table 3 reveals that responses on Trial N are assimilated to stimulus values on Trials N-1 and N-2, and are contrasted with stimuli 3 through 6 trials back in the sequence.

Table 4 shows the same analysis as Table 3 but performed this time with respect to the previous responses in the sequence of category judgments. In order to enhance comparability with data from previous studies, this analysis was done on the average error of response on Trial N. The correlation coefficients again are shown in order to indicate the direction and reliability of the contrast and assimilation effects. As found by Ward and Lockhead (1970b), the response analysis reveals assimilation extending as far as five trials back in the stimulus series.

Table 5 shows an analysis of the effects of previous stimuli compara-

Table 4

Average Error of Responses in the Category Judgment Experiment as a Function of the Response on Trial N-K (K = 1, 6)

Response on Trial N-K	Average Error on Trial N					
	K = 1	K = 2	K = 3	K = 4	K = 5	K = 6
1	-2.12	-1.92	-1.79	-1.64	-1.70	-1.48
2	-2.05	-1.83	-1.73	-1.69	-1.51	-1.60
3	-1.78	-1.69	-1.58	-1.65	-1.68	-1.56
4	-1.48	-1.50	-1.49	-1.55	-1.52	-1.67
5	-1.26	-1.36	-1.58	-1.57	-1.78	-1.68
6	-1.09	-1.36	-1.74	-1.63	-1.59	-1.69
7	-1.05	-1.46	-1.47	-1.58	-1.71	-1.73
8	-1.05	-1.51	-1.46	-1.43	-1.71	-1.70
9	-.67	-1.31	-1.67	-1.37	-1.33	-1.65
10	-.37	-1.05	-1.35	-1.04	-.83	-1.47
r' =	.983	.888	.616	.809	.558	-.223

Note.--Also shown are the rank-order correlation coefficients between the average error on Trial N and the stimulus value on Trial N-K. There are 9 degrees of freedom for each r'.

Table 5

Average Responses in the Magnitude Estimation Experiment as a Function of the Stimulus on Trial N-K (K = 1, 6)

Stimulus on Trial N-K	Average Response on Trial N					
	K = 1	K = 2	K = 3	K = 4	K = 5	K = 6
1	1.93	2.11	2.08	2.16	2.23	2.29
2	2.39	2.17	2.31	2.36	2.36	2.28
3	2.67	2.81	2.73	2.57	2.55	2.71
4	2.07	2.10	2.04	2.24	2.26	2.26
5	2.43	2.37	2.62	2.30	2.86	2.48
6	2.43	2.63	2.34	2.45	2.32	1.85
7	2.28	2.33	2.47	2.41	2.21	2.38
8	2.51	2.62	2.46	2.69	2.63	2.59
9	2.49	2.39	2.46	2.40	2.22	2.12
10	3.63	2.99	2.88	2.54	2.46	2.51
r' =	.634	.576	.527	.552	-.006	.067

Note.--Also shown are the rank-order correlation coefficients between the average responses on Trial N and the stimulus value on Trial N-K. There are 9 degrees of freedom for each r'.

ble to that in Table 3, page 33, but performed on the average responses in the magnitude estimation situation. It can be seen that the overall sequential effects for the magnitude estimation situation are quite similar to those in the category judgment situation, with the exception that assimilation for magnitude estimations seems to extend as far back as four trials, and they do not seem to change to contrast at that point, but rather stop. The analysis for the effects of previous responses was not done for the magnitude estimation data since it is not appropriate to that method.

Symmetry analysis. In the magnitude estimation experiment, subjects were asked to produce responses according to the rule $R(N) = R(N-1) \cdot S(N)/S(N-1)$. We can get an estimate of the subject's judgment of the ratio of the stimulus on Trial N [S(N)] to the stimulus on Trial N-1 [S(N-1)] by finding the ratio of the response on Trial N [R(N)] to the response on Trial N-1 [R(N-1)]. If the subject was doing the task consistently and well, then the ratio of responses for a particular pair of stimuli N-1 and N in the stimulus series, say 1 and then 10, should be the reciprocal of the ratio of responses when that pair of stimuli occurred in the reverse order, 10 and then 1. If this situation obtained, the geometric mean of the two fractions in question would be equal to one. For the purposes of the present paper, this situation will be defined as "symmetry." It is possible, in view of the variability of responses, that even when an average of a large number of occurrences of a particular pair of stimuli is taken, the geometric mean fraction will not be equal to one. This situation is

considered to be "asymmetry" of the fractions. When the geometric mean fraction is less than 1, this is defined as "negative asymmetry"; when it is greater than 1, as "positive asymmetry." Asymmetry can be interpreted as judgment error; positive asymmetry implies overestimation, negative implies underestimation.

Table 6 presents the results of the analysis of fractions for symmetry. Each entry in the table is the average over all 8 subjects of the log geometric mean fraction estimated from adjacent responses for a particular ordered pair of stimuli. There are approximately 40 observations per entry. Since the averages of the logarithms of the fractions are entered in the table, the average of a complementary pair (e.g., 1-10, 10-1) of entries would have to be equal to zero for symmetry to obtain. If perfect symmetry obtained for the entire matrix, the main diagonal (stimulus repeats) would be all zeros and the rest of the matrix would be symmetric about the main diagonal, with the exception of a change of sign from positive in the upper right to negative in the lower left. Inspection of the matrix reveals that symmetry does not generally obtain.

In order to check for a pattern in the symmetry violations, the geometric means of the two fractions (one for each order of presentation) of each of the 45 off-diagonal complementary pairs was calculated. These numbers, along with the uncombined fractions of the repeated pairs, are referred to hereafter as "symmetry numbers." There were 55 symmetry numbers for analysis (45 from the off-diagonal complementary pairs and 10

Table 6

Average Log R(N)/R(N-1) for All Combinations of S(N) and S(N-1) for the Magnitude Estimation Data

Stimulus Value on Trial N-1	Stimulus Value on Trial N									
	1	2	3	4	5	6	7	8	9	10
1	-.17	-.03	.05	.12	.20	.31	.38	.48	.61	.87
2	-.25	-.09	.00	.03	.16	.21	.26	.41	.56	.81
3	-.30	-.18	-.04	.02	.06	.13	.18	.33	.40	.70
4	-.35	-.23	-.10	.00	.00	.08	.18	.26	.43	.67
5	-.43	-.25	-.17	-.08	-.04	.04	.12	.20	.39	.63
6	-.47	-.30	-.26	-.19	-.08	.00	.05	.14	.28	.55
7	-.47	-.37	-.25	-.24	-.13	-.09	-.01	.11	.28	.52
8	-.64	-.38	-.39	-.23	-.19	-.10	-.08	-.03	.12	.40
9	-.46	-.51	-.40	-.33	-.26	-.25	-.13	-.08	.04	.26
10	-.71	-.57	-.52	-.41	-.35	-.25	-.29	-.19	-.09	.10

Note.--Each entry is the average of about 40 observations.

from the repeats). The Spearman rank order correlation coefficient (r') between the symmetry numbers and several relevant factors was calculated. The symmetry numbers are correlated positively with a measure of the total energy of the two stimuli (the sum of the stimulus magnitudes in millivolts) of each symmetry number ($r' = .915$, $df = 54$, $p \approx 10^{-5}$). The symmetry numbers range from quite negative for stimulus pairs with a low total energy to quite positive for stimulus pairs with a high total energy. The greater the total energy of the stimulus pair whose symmetry number is considered, the more positive the asymmetry, i.e., the more the ratios are overestimated. The symmetry numbers are also correlated with other factors (e.g., the difference in millivolts between the stimulus pair, the ratio between the pair, the stimulus value, etc.), but these in turn are correlated with total energy. Total energy handles more variance as a single factor than does any other variable. The correlation coefficients of the individual subjects were in all cases in the same direction as the coefficient for the average data, although generally slightly closer to zero because of the greater variability in the data of the individual subjects.

This analysis is not really relevant to the category judgments, since in that task subjects were not instructed to pay attention to the ratios between stimuli. However, in view of the similarity of the data from the two methods so far, the analysis was performed on the category judgments in the same fashion as for the magnitude estimation data above. Table 7 presents the results of this analysis. It can be seen that the results take

Table 7

Average Log R(N)/R(N-1) for All Combinations of S(N) and S(N-1) for the Category Judgment Data

Stimulus Value on Trial N-1	Stimulus Value on Trial N									
	1	2	3	4	5	6	7	8	9	10
1	-.08	.02	.06	.18	.27	.35	.46	.57	.65	.82
2	-.13	-.06	-.01	.05	.12	.26	.34	.45	.57	.65
3	-.18	-.15	-.05	.02	.05	.17	.25	.55	.41	.54
4	-.28	-.18	-.11	-.01	.02	.11	.15	.26	.47	.52
5	-.34	-.22	-.21	-.11	-.06	.06	.14	.20	.47	.50
6	-.40	-.24	-.18	-.14	-.06	.01	.09	.10	.26	.40
7	-.47	-.31	-.24	-.20	-.13	-.08	.04	.07	.19	.29
8	-.58	-.36	-.33	-.24	-.20	-.21	-.06	-.01	.13	.23
9	-.55	-.52	-.38	-.37	-.31	-.23	-.16	-.07	.03	.10
10	-.78	-.65	-.50	-.41	-.42	-.30	-.22	-.16	-.05	.02

Note.--Each entry is the average of about 40 observations.

exactly the same form for category judgments as for magnitude estimations. The matrix is not symmetric. Once again, the calculated symmetry numbers correlate positively with the total energy of the relevant pairs of stimuli ($r' = .815$, $df = 54$, $p \approx 10^{-5}$).

Modulus drop. The fact that the modulus dropped for all eight subjects, as demonstrated in the section on time order error, implies that there was an overall negative asymmetry of fractions for each subject. To investigate this, the geometric mean of all the fractions (100 of them, 10 repeats plus 90 off-diagonals) was calculated for each individual subject. In each case, the geometric mean fraction was less than 1.

For each subject, the last judgment in this task was a judgment of stimulus number 5. The response to this stimulus is an indication of the modulus level at the end of the session, and thus should correlate positively with the overall geometric mean fractions of the subjects. The rank order correlation between the subjects' responses to the last stimulus (5) and their geometric mean fractions was .96 ($df = 7$, $p = .011$).

Possible confounding. Since, in all cases, subjects judged single stimuli and differences according to category judgment instructions before making their magnitude estimations, it is possible that some transfer of training was responsible for the remarkable similarity of the results in the two experiments. It is also possible that requiring subjects to report a number for each stimulus, rather than just the ratio between two stimuli, had some effect on the way the subjects responded. To check these

possibilities, an additional subject judged the same stimuli by the method of magnitude estimation only. This subject performed the magnitude estimation task in a slightly different way. Instead of calculating a response from the judged ratio of two stimuli and the previous response, he was asked to report only that judged ratio. Thus his responses themselves were fractions, or ratios between stimuli adjacent in the stimulus series.

The data of this subject were analyzed in the same way that the data in the main experiment were analyzed. The results were identical in form to those of the eight subjects in the main experiment. Because this subject could not see that the modulus was changing, he should display a larger modulus drop than the other subjects, who claimed to be compensating for the modulus drop. In fact, this subject's modulus dropped three orders of magnitude (from an arbitrary beginning point of "10") in the first 40 trials and continued to drop over the remaining 460 trials. His overall geometric mean fraction was smaller than any other subject's (.97 as opposed to an average of .99 for the others). Thus he displayed by far the largest modulus drop and the smallest geometric mean fraction.

DISCUSSION

The present study has investigated the relation between category judgment and magnitude estimation in an effort to understand the psychological processes involved in making psychophysical judgments by the two methods. It has been found that, even though the instructions to the subject differ greatly from one method to the other, the basic psychophysical data are similar in many ways. Both methods show the classical effects of time order error and central tendency. Responses in both situations are subject to the effects of the previous sequence of stimuli and responses. And, in both situations, symmetry of ratios between stimuli does not generally obtain, and the asymmetry of the ratios is correlated with the total energy of the relevant stimulus pairs. These results indicate a striking similarity in the fundamental judgment processes of the two methods.

Response variance. Another relevant property of the data is the pattern of response variance to the different stimuli. Typically, response variance in category judgments increases as the magnitude of the stimulus increases, with the exception that it generally decreases again near the upper end of the stimulus range. The small variance at the ends of the

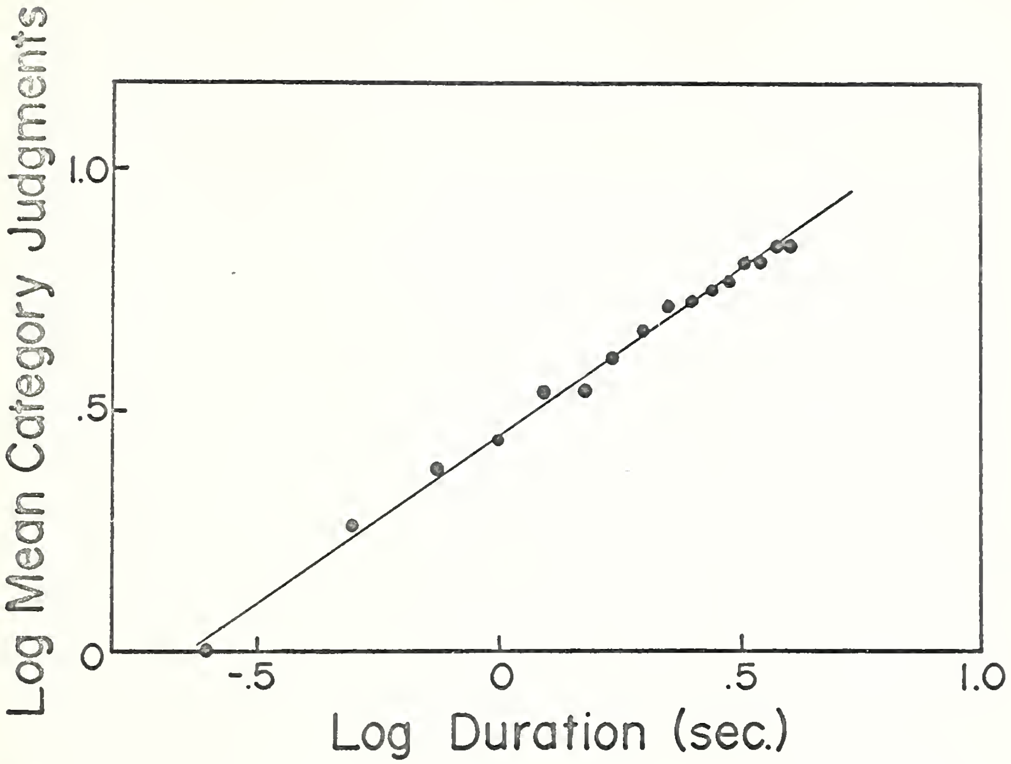
scale is generally attributed to end effects; the overall increase is attributed to the decrease in discriminability with increasing stimulus magnitude (Weber's Law). Eisler (1963) has reported data on category judgments and magnitude estimations of line lengths in which he finds this traditional pattern for both category judgments and magnitude estimations of line lengths. The data of the present study also show the effect for the category judgments, but not generally for the magnitude estimations. For 7 of the 8 subjects in the magnitude estimation experiment, response variance seems to increase steadily with increasing stimulus magnitude. However, a distinct end effect, or decrease in response variance at the top of the stimulus range, is visible in the data of the subject who displays the smallest modulus drop. The modulus drop artificially increases the response variance to the large stimuli more than that to the smaller stimuli, resulting in the steady increase of response variance with stimulus magnitude observed in the results of the magnitude estimation experiment. In magnitude estimation studies like Eisler's (1963), however, in which the modulus changes very little, response variance shows the same pattern as that observed in category judgment data.

Power law. This study represents yet another confirmation of the psychophysical power law. The data presented here show, to a good approximation, that a power function is a good fit to judgments of loudness. This common finding can now be extended to category judgments as well, since several investigators have found good fits of power functions to category

judgment data (Curtis, 1970; this study). Even category judgments collected by Stevens are well fit by a power function. Figure 5 shows data from category judgments of line lengths and durations replotted from Stevens and Galanter (1957) in log-log coordinates. The psychophysical functions are clearly very close to straight lines in these coordinates, which means that they are very close to being power functions.

One ubiquitous finding remains unexplained however: the difference in the exponents of power functions fitted to category judgment and magnitude estimation data. The present study found that the exponent for magnitude estimations was almost exactly twice that of category judgments of the same stimuli. Table 8 shows that this is a more common finding than might be imagined. For six different prothetic perceptual continua, the ratio between the exponents is almost exactly 2:1. The explanation for this finding may lie in the difference between what the two methods require the subjects to do with the basic sensory event, i.e., in how they map the sensation or perception onto the response scale in use in the particular experiment. One variable that might affect the mapping is the range of responses available for use by the subject. Experimenters typically limit the response domain in category judgment to 7-10 categories, and thus to the response numbers 1-7 or 1-10. In magnitude estimation the subject is free to use any positive real number as a response. Stevens and Galanter (1957) present evidence that the category scale approaches linearity with the magnitude scale as the number of responses allowed in the category judgment situation

Fig. 5. Data from Category Judgment Experiments on the Continua of Duration and Line Length, Replotted in Log-Log Coordinates from Stevens and Galanter (1957). The straight lines have slopes of about .55 (duration) and .66 (line length); these are the category judgment exponents for these continua entered in Table 8.


Log Mean Category Judgments
1.0
.5
0
-.5
0
.5
1.0
Log Duration (sec.)

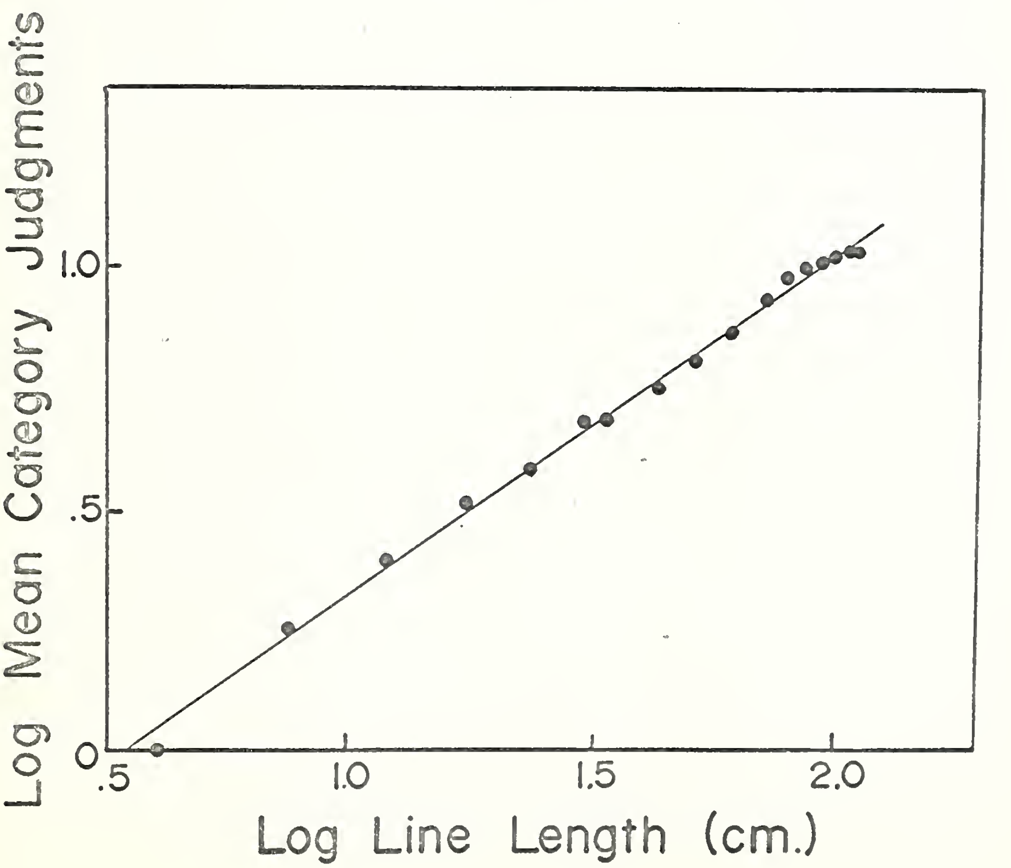

Log Mean Category Judgments
1.0
.5
0
.5
1.0
1.5
2.0
Log Line Length (cm.)

Table 8

Exponents of Power Functions Fitted to Data of Category Judgments and Magnitude Estimations for Six Perceptual Continua

Continuum	Category Judgment Exponent	Magnitude Estimation Exponent
Duration	.55[a]	1.10[a]
Line length	.66[a]	1.10[a]
Brightness	.13[b]	.26[b]
Lightness of gray	.42[c]	.85[d]
Heaviness	.72[e]	1.45[a]
Loudness	.39[f]	.78[f]

Note.--Exponents presented are from the same study where possible (duration, line length, brightness, and loudness). For lightness of gray and heaviness, the magnitude estimation exponents are from studies reporting more typical exponents than those found in the studies from which the category judgment exponents were taken.

a. Stevens and Galanter, 1957.

b. Curtis, 1970.

c. Torgerson, 1961.

d. Mashour and Hosman, 1968.

e. Curtis *et al.*, 1968.

f. This study.

approaches that of the magnitude estimation situation.

An important implication of the finding of a constant ratio between the exponents of the two scales is that category judgments will predict cross-modality matching exponents for prothetic continua equally as well as do magnitude estimations. Since the prediction of cross-modality matching exponents was a large feature in arguments for the validity of the magnitude scale, the category scale is rendered equally valid.

Sequential effects. The data of both methods of judgment display the effects of the previous sequence of stimuli on the response to the present stimulus. The response to the present stimulus is assimilated to the value of the previous stimulus in both studies, and to the value of the previous response as well in the category judgment study. The effect changes to one of contrast with the stimulus values four and more trials back in the sequence in the category judgment situation. It seems to be absent after four trials back in the magnitude estimation situation. In the category judgment situation, assimilation to the previous responses lasts as far as five trials back in the sequence.

The sequential effects for the category judgment situation are almost exactly the same as those found by Holland and Lockhead (1968) and Ward and Lockhead (1970a, 1970b) for absolute judgments in which there was an identification function present from stimuli to responses. Ward and Lockhead (1970b) proposed that these sequential effects are due to two response system processes employed in producing a response in the presence

of uncertainty of the "correct" response. The first is a process of guessing responses to succeeding stimuli that are closer to each other than would be expected if the subject were probability matching his response differences to the expected distribution of differences in category steps between stimuli adjacent in the sequence. This necessarily results in assimilation of responses to the previous stimulus and response; the effect is compounded to other stimuli and responses in the sequence if the previous response is used as an estimate of the value of the previous stimulus. The second is a process of trying to use the available responses equally often, which would result in contrast with the previous stimuli and responses. Presumably the assimilation and contrast observed in the category judgment data arise from these sources as well.

It is quite possible that the tendency to use responses that are closer together than demanded by the stimuli could be operating to produce the assimilation in the magnitude estimation situation. This tendency would be expected if the subject was paying attention to the differences between pairs of stimuli and had learned the expected distribution of differences between stimuli in a random sequence. No contrast effects were observed in the magnitude estimation data. This is presumably because, in a situation where the response set is practically unlimited, there is no tendency to use all responses equally often, and thus no contrast.

The fact that both judgment situations give rise to assimilative effects implies that the locus of the bias lies in a fundamental judgment process

common to the two situations. Subjects are judging pairs of stimuli as more similar than they would be judged in the absence of this bias. This could mean that the memories of the previous and present stimulus, or the memory of the previous and the "perception" or "sensation" of the present one, are assimilated toward each other. Since Ward and Lockhead (1970b) found the same biases operating in a guessing situation, however, it is more likely that the underestimation results from aberrations in the subjects' construction of some underlying difference scale (see next section). The source of the aberrations may lie in the subjects' attempts to maximize with respect to the expected distribution of differences between previous and present stimuli.

Symmetry analysis. It was shown above that the geometric means of ratios of complementary pairs of stimuli, the symmetry numbers, were not generally equal to one, i.e., the ratio judgments were not generally symmetric for the data of either experiment. The pattern of symmetry violations was identical in both experiments; asymmetry changed from quite negative through zero to quite positive as the total energy of the stimulus pair, responses to which were used to calculate the ratios, increased. Why this happened will be the subject of another paper. For the present it is observed that the result implies similar underlying processes of judgment in the two methods. Since category judgment presumably forces subjects to ignore ratios (Stevens, 1966), it seems likely that the judgment process common to both methods is a process of category or interval judgment.

I propose that a process of comparative category judgment of differences (or distances) between pairs of stimuli underlies the two types of judgment. Distances and ratios between pairs of stimuli in a stimulus set are monotonically related; in fact ratios are differences in the logarithmic transfer domain. It is possible that, in the magnitude estimation situation, subjects first make category judgments of the distance between the immediately previous stimulus and the present stimulus. They would then have to map this distance judgment onto another number scale representing ratios between stimuli. The number obtained from this second scale would then be used as a ratio in the production of a response according to the multiplicative rule of judgment of that situation.

In the category judgment situation, comparative judgment of the difference between the previous and present stimulus in category units, along with knowledge of the previous stimulus value (or an estimate based on the previous response), could be used to obtain a response to the present stimulus by algebraic addition. Thus the mapping from the basic judgment scale into the actual responses would differ in the two methods according to the rule of judgment employed. This may be the source of the difference in exponents between the two methods for the same continuum.

The above proposal is very similar to one put forth by Torgerson (1961) who argues that subjects can only perceive a single fundamental relation between a pair of stimuli and that they interpret it according to the rules of the judgment situation. I am proposing that the relation perceived

is a difference or distance, that it is always judged in terms of categories constructed for the particular stimulus situation, and that the difference in interpretation of the basic sensory event comes only after the fundamental judgment process has been completed. Thus the difference between the two methods is argued to be of a higher order than that suggested by Torgerson (1961).

Different types of psychophysical scales have been said to result from different rules of matching stimuli to responses in a psychophysical judgment task. If the above analysis is correct, it would seem that simply giving subjects different sets of instructions may not assure that they are doing anything fundamentally different when judging the stimuli. Magnitude estimation has been supposed to result in a ratio scale, and category judgment in an interval scale. However, if the same fundamental judgment process is producing responses in both situations, then the scales given rise to by the two methods cannot be of different types. If this fundamental judgment process is category judgment of differences, then both scales can be at most interval scales.

APPENDIX

CURVE FITTING PROGRAM

The computer program used in fitting the equation $R = aS^N + b$ to the data of the two experiments is reproduced on the following pages. It is written in Fortran IV and was run on an IBM 360/75 computer.

The equation to be fitted is a power function with three parameters. To get a least-squares fit, we would solve for the values of the parameters a, N, and b, minimizing Q, where

$$Q = \sum_{i=1}^{n} [R_i - (aS_i^N + b)]^2,$$

and the R_is are the average responses and the S_is are the stimulus values in millivolts. Minimizing the above equation involves taking the partial derivatives of the equation with respect to each of the parameters and then solving the three simultaneous equations that result from setting the partial derivatives equal to zero. There is no easy analytic solution to these equations. In the program reproduced here, the minimizing values of the parameters are reached by a process of successive approximation. This program was supplied to the author of the present paper by Dwight Curtis of the California State College at Fullerton. It was used to analyze data in

the studies of Curtis, 1970, Curtis *et al.*, 1968, and Curtis and Fox, 1969. A copy of the additional instructions necessary to use the program are also reproduced here, as well as a sample of the output using data from the category judgment experiment.

NON LINEAR LEAST SQUARES CURVE FITTING

Deck Setup

* 1. Program with appropriate header cards

* 2. NSTART

* 3. NSTOP .. The latter two cards, Format (6X, I2), are control cards which enable one to analyze successively several sets of data. There is one NSTART card for each job and one NSTOP card before each data set. An additional NSTOP card follows the final data deck. The program performs the test, IF(NSTOP.GT.NSTART) STOP, upon each NSTOP card. The program will analyze each set of data in turn as long as the value assigned to NSTOP is smaller than the value assigned to NSTART. By assigning a value to the final NSTOP card exceeding the value of NSTART, the program is instructed to terminate.

* 4. TITLE card Format (4X, 19A4)

* 5. This is a parameter card, punched in Format(8I4). It contains a number of indexes employed by the program, as follows:

a. N - the number of values on the dependent variable (Scale values).

b. L - the number of independent variables. For the data of the standard experiment involving magnitude estimations of stimuli L = 1. Where judgments of differences or sums are involved L = 2. The program, in its present form, will handle as many as six independent variables.

c. IW - this is a weighting factor, employed to weight the squared deviations differentially when this is necessary because the data are not consistent with assumptions of the regression model. IW can assume several different values:

1) If IW is negative (e.g., -2) the weight for a particular observation is made equal to J**IW ($J^{-2} = 1/J^2$). In the example, the effect would be to minimize the sume of the squared relative deviations, $\sum((J-J')/J)^2$. This would have approximately the same effect as a least squares fit to the logarithms of the observations.

2) If IW = 0, all weights are made equal to 1, and an unweighted solution is obtained.

3) If IW is positive, the program is instructed to read a card defining a format, followed by cards containing weights to be read by that format. This adds to the flexibility of the program, but I have not found it to be particularly useful.

d. NP - the number of parameters in the equation to be fitted.

e. NPX - the number of parameters to be held constant. One may assign values to one or more parameters, estimating the values of the remaining parameters.

f. SS1 - an index which enables one to constrain the variation of parameter estimates over successive iterations. If SS1 is negative (e.g., -1) the program reads two vectors, UAP and LAP, which will constitute the highest values and the lowest values that the parameters will be permitted to assume. By setting UAP and LAP, one is sometimes able to avoid divergent iterative sequences or inappropriate parameter values (such as negative exponents) which may lead the program to fail to achieve a solution. Caution: the range established by UAP and LAP must include the parameter value; otherwise no solution will be achieved. If SS1 is set to zero or is positive, no constraints are imposed and no cards defining UAP or LAP are included in the deck.

g. XREP - an index to indicate the form in which the data are to be read by the input subroutine (Subroutine Obs). Where the raw data are employed, the subroutine will average over replications (geometric means) if XREP is assigned a zero or negative value. If XREP is positive,[1] OBS will read a single vector of scale values.

* 6. Test (Format(E11.3)) Test provides the criterion employed by the program in determining when a satisfactory fit has been achieved. On each iteration, the relative change on each parameter is compared with test, and when the change (relative to the value of the parameter) becomes smaller than TEST on all parameters, the program transfers to the output routine. We have customarily a criterion of .0001.

* 7. Initial parameter estimates - Format(8F10.6) - These represent ones best guesses concerning the values of the parameters. Usually they don't have to be very close. Occasionally, however, bad estimates will initiate a divergent iterative series which lead to the termination of the analysis. By setting UAP and LAP, this can usually be avoided.

8. UAP - Upper limits - Format(8F8.3). One vale must be given for each parameter if they are used at all.

9. LAP - Lower limits - same as above.

10. IDA - Format(8I4) - A vector of number of the parameters to be held constant. This card is appropriate <u>only</u> if NPX (card #5) is given a nonzero value. If, for instance, one wished to estimate parameters AP(1), AP(2), and AP(4), holding AP(3) constant, a three (3) would placed in column 12 of this card.

* 11. FMT1 - Format. The program is written in variable format. FMT1 provides a format to read a vector of values on the independent variable (   ). If two or more independent variables are used, as in the difference judgment situation, the program reads the first series, the second series, etc. These are placed in an N x L matrix.

* 12. Vector of independent variable values.

* 13. FMT2 - Format - for reading data.

* 14. Data deck.

15. FMT3 - Format for reading weights. This format card is employed <u>only</u> when one assigns weights to observations consistent with IW = positive.

16. W - weights to be assigned to observations. Used in conjunction with #15, above, and IW = positive.

* The item with asterisks Above must be present in every deck setup. These not asterisked may or may not be used, depending upon what constraints the processor wishes to impose.

<u>Function Subroutine</u>

The function subroutine is called FCN. It has four arguments, as follows:

First (X) is a one-dimensional array giving values of the independent variables.

Second (AP) is a one-dimensional array of current estimates of the parameters.

Third (F) is the name of the function.

Fourth (FP) is a one-dimensional array of the partial derivatives of the function with respect to the parameters.

```
C  LEAST SQUARES CURVE FIT  (REGRESSION)
C  NON-LINEAR WITH SEVERAL INDEPENDENT, ONE DEPENDENT VARIABLE
      DIMENSION IDA(6),FP(6),AP(6),D(6),P(6,6),T(1000),Z(8)
      DIMENSION TITLE(19),UAP(8),LAP(8)
      COMMON N,NP,L,IDA,AP,IW,TEST,NPX,FACT,D,P,NPV,T,GF,ICOUNT
      READ (1,625) NSTART
  600 READ (1,625) NSTOP
      IF(NSTOP.GT.NSTART) STOP
  625 FORMAT (6X,I2)
      READ (1,630) (TITLE(I),I=1,19)
  630 FORMAT (4X,19A4)
      WRITE(3,631) (TITLE(I),I=1,19)
  631 FORMAT(1H0,19A4)
  650 FACT=1.0
      READ (1,821) N,L,IW,NP,NPX,SS1,IREP
  821 FORMAT (8I4)
      READ (1,819) TEST
  819 FORMAT (F10.8)
      READ (1,822) (AP(I),I=1,NP)
  822 FORMAT (8F10.6)
      IF(SS1) 623,635,635
  623 READ (1,624)(UAP(I),I=1,NP)
      READ (1,624)(LAP(I),I=1,NP)
  624 FORMAT (8F8.3)
  635 IF(NPX) 10,10,8
   10 DO 9 I=1,NP
    9 IDA(I)=0.
      GO TO 801
    8 READ (1,821) (IDA(I),I=1,NP)
  801 CALL OBS (L,N,IREP,IW,T)
C  CALCULATION SECTION
C  GENERATE LINEARIZED EQUATIONS
      ICOUNT=1
   23 DO 20 I=1,NP
      D(I)=0.
      DO 20 J3=1,NP
   20 P(I,J3)=0.
      WVAR=0.
  704 DO 21 J3=1,N
  701 LW=N+J3
      W=T(LW)
      Y=T(J3)
      DO 899 LI=1,L
      LW=LW+N
  899 Z(LI)=T(LW)
  703 CALL FCN(Z,AP,F,FP)
      AF=Y-F
      WVAR=W*AF*AF+WVAR
      DO 22 J2=1,NP
      F=W*FP(J2)
      D(J2)=AF*F+D(J2)
      DO 22 J1=1,NP
   22 P(J1,J2)=F*FP(J1)+P(J1,J2)
   21 CONTINUE
```

```
      NPV=NP-NPX
      J2=0
      DO 41 I=1,NPV
   42 J2=J2+1
      IF(IDA(J2)) 42,43,42
   43 D(I)=D(J2)
      J3=0
      DO 41 J1=1,NPV
   44 J3=J3+1
       IF(IDA(J3)) 44,45,44
   45 P(I,J1)=P(J2,J3)
   41 CONTINUE
      IF(NPX) 47,848,47
   47 I=NPV+1
      DO 48 J2=1,NP
      DO 48 J3=1,NP
   48 P(J2,J3)=0.
  848 J3=NPV-1
C  SOLVE SYSTEM OF EQUATIONS
      P(1,1)=1.0/P(1,1)
      IF(J3) 210,13,100
  100 DO 110 J2=1,J3
      DO 101 I=1,J2
      F=0.
      DO 102 J1=1,J2
  102 F=P(I,J1)*P(J1,J2+1)+F
  101 FP(I)=-F
      F=P(J2+1,J2+1)
      DO 103 I=1,J2
  103 F=P(I,J2+1)*FP(I)+F
      F=1.0/F
      P(J2+1,J2+1)=F
      DO 104 I=1,J2
      DO 104 J1=1,J2
  104 P(I,J1)=FP(I)*FP(J1)*F+P(I,J1)
      DO 110 I=1,J2
      P(I,J2+1)=FP(I)*F
  110 P(J2+1,I)=P(I,J2+1)
   13 DO 134 I=1,NPV
      FP(I)=0.
      DO 134 J1=1,NPV
  134 FP(I)=D(J1)*P(J1,I)+FP(I)
C  COMPUTE NEW PARAMETER VALUES
      J2=2
      J1=0
      DO 155 I=1,NPV
  151 J1=J1+1
      IF(IDA(J1)-J1) 150,151,150
  150 F=FACT*FP(I)+AP(J1)
      IF(SS1) 620,154,154
  620 IF(UAP(J1).GT.F) GO TO 622
      F=(AP(J1)+UAP(J1))/2
      GO TO 401
  622 IF(F.GT.LAP(J1)) GO TO 154
```

```
      F=(AP(J1)+LAP(J1))/2
      GO TO 401
  154 AF=(AP(J1)-F)/AP(J1)
      IF(AF) 300,402,400
  300 AF=-AF
  400 IF(AF-TEST) 402,402,401
  401 J2=1
  402 AP(J1)=F
  155 CONTINUE
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GE.50) GO TO 690
      GO TO (23,210),J2
  690 WRITE(3,691)
  691 FORMAT (33H MAXIMUM NO OF ITERATIONS REACHED)
C  OUTPUT SECTION
  210 IF(IW) 773,774,773
  773 WRITE(3,842)
  842 FORMAT (15HJPOINT   WEIGHT7X,4HX(1)11X,1HY10X,8HFUNCTION5X,9HABS.
     1DIFF3X,8HREL DIFF)
      GO TO 871
  774 WRITE(3,742)
  742 FORMAT (7HJ POINT 5X,5H X(1)11X,2H Y10X,9H FUNCTION5X,10H ABS.DIFF
     1 3X,9H REL DIFF)
  871 VAR=0.
      WVAR=0.
  731 DO 207 J3=1,N
  733 LW=N+J3
      W=T(LW)
      Y=T(J3)
      DO 898 LI=1,L
      LW=LW+N
  898 Z(LI)=T(LW)
  735 CALL FCN(Z,AP,F,FP)
      AF=Y-F
      VAR=AF*AF+VAR
      WVAR=W*AF*AF+WVAR
      BF=AF/F
      IF(IW) 714,715,714
  714 WRITE(3,841) J3,W,Z(1),Y,F,AF,BF
  841 FORMAT(1X,I4,2X,E10.3,1X,3(E13.6,1X),E12.5,1X,F7.3)
      GO TO 207
  715 WRITE(3,716) J3,Z(1),Y,F,AF,BF
  716 FORMAT(1X,I4,2X,4(E13.6,1X),F7.3)
  207 CONTINUE
      WRITE(3,761)
  761 FORMAT(1HK25X,20H INVERSE OF P MATRIX)
      DO 751 J3=1,NPV
  751 WRITE(3,762) (P(J3,LI),LI=1,NPV)
  762 FORMAT(1X,6(E13.6,1X))
      AF=N-NPV
      VAR=VAR/AF
      WVAR=WVAR/AF
      WRITE(3,843) VAR,WVAR
  843 FORMAT(13HK VARIANCE = E13.6,2X,21H WEIGHTED VARIANCE = E13.6/)
```

```
      IF(ICOUNT.GE.50) GO TO 600
      J1=0
      DO 208 I=1,NPV
  209 J1=J1+1
      D(J1)=0.
      IF(IDA(J1)-J1) 208,209,208
  208 D(J1)=SQRT(WVAR*P(I,I))
      DO 211 I=1,NP
  211 WRITE(3,844) I,AP(I),D(I)
  844 FORMAT(6H PARAM I2,4H  = E15.8,3X,17HSTANDARD ERROR = E12.5)
      WRITE(3,692) ICOUNT
  692 FORMAT(14H ITERATIONS = I2)
      GO TO 600
      END
```

```
      SUBROUTINE OBS (L,N,IR,IW,T)
      DIMENSION SY(110),FMT1(20),FMT2(20),FMT3(20),Z(110),Y(110),W(110),
     1T(1000)
      READ(1,822) (FMT1(I),I=1,20)
  822 FORMAT(20A4)
      I=2*N
      DO 310 K=1,L
      READ(1,FMT1) (Z(J),J=1,N)
      DO 311 K2=1,N
  311 T(I+K2)=Z(K2)
  310 I=I+N
      DO 313 I=1,N
  313 SY(I)=0.0
      READ(1,822) (FMT2(I),I=1,20)
      DO 314 I=1,IR
      READ(1,FMT2) (Y(J),J=1,N)
      IF(IR.EQ.1) GO TO 312
      DO 315 K=1,N
  315 SY(K)=SY(K)+ALOG(Y(K))
  314 CONTINUE
      DO 316 K=1,N
  316 Y(K)=EXP(SY(K)/IR)
  312 DO 317 K=1,N
  317 T(K)=Y(K)
      IF(IW) 318,319,320
  318 DO 321 I=1,N
  321 T(N+I)=T(I)**IW
      RETURN
  319 DO 322 I=1,N
  322 T(N+I)=1.0
      RETURN
  320 READ(1,822) (FMT3(I),I=1,20)
      READ(1,FMT3) (W(J),J=1,N)
      DO 323 I=1,N
  323 T(N+I)=W(I)
      RETURN
      END
```

```
      SUBROUTINE FCN (Z,AP,F,FP)
      DIMENSION AP(3),FP(3)
      FP(1)=Z**AP(2)
      A=AP(1)*FP(1)
      F=A+AP(3)
      FP(2)=A*ALOG(Z)
      FP(3)=1.0
      RETURN
      END
```

CATEGORY JUDGMENTS OF SINGLE STIMULI - SUBJECT NO. 2 - MEANS

POINT	X(1)	Y	FUNCTION	ABS.DIFF	REL DIFF
1	0.310000E 00	0.158000E 01	0.208369E 01	-0.503695E 00	-0.242
2	0.615000E 00	0.238000E 01	0.230888E 01	0.711203E-01	0.031
3	0.119000E 01	0.292000E 01	0.258255E 01	0.337449E 00	0.131
4	0.235000E 01	0.302000E 01	0.293821E 01	0.817909E-01	0.028
5	0.460000E 01	0.360000E 01	0.338156E 01	0.218440E 00	0.065
6	0.910000E 01	0.422000E 01	0.395055E 01	0.269449E 00	0.068
7	0.179000E 02	0.458000E 01	0.466399E 01	-0.839863E-01	-0.018
8	0.350000E 02	0.498000E 01	0.555629E 01	-0.576288E 00	-0.104
9	0.690000E 02	0.666000E 01	0.669659E 01	-0.365934E-01	-0.005
10	0.136000E 03	0.836000E 01	0.813766E 01	0.222341E 00	0.027

INVERSE OF P MATRIX

0.254641E 01	-0.346037E 00	-0.285155E 01
-0.346037E 00	0.478399E-01	0.380023E 00
-0.285155E 01	0.380023E 00	0.336180E 01

VARIANCE = 0.127083E 00 WEIGHTED VARIANCE = 0.127083E 00

PARAM 1 = 0.12641392E 01 STANDARD ERROR = 0.56886E 00
PARAM 2 = 0.34538805E 00 STANDARD ERROR = 0.77972E-01
PARAM 3 = 0.12401323E 01 STANDARD ERROR = 0.65363E 00
ITERATIONS = 9

CATEGORY JUDGMENTS OF SINGLE STIMULI - SUBJECT NO. 4 - MEANS

POINT	X(1)	Y	FUNCTION	ABS.DIFF	REL DIFF
1	0.310000E 00	0.106000E 01	0.115182E 01	-0.918226E-01	-0.080
2	0.615000E 00	0.142000E 01	0.145988E 01	-0.398760E-01	-0.027
3	0.119000E 01	0.196000E 01	0.182491E 01	0.135091E 00	0.074
4	0.235000E 01	0.238000E 01	0.228746E 01	0.925379E-01	0.040
5	0.460000E 01	0.292000E 01	0.284958E 01	0.704231E-01	0.025
6	0.910000E 01	0.336000E 01	0.355282E 01	-0.192817E 00	-0.054
7	0.179000E 02	0.442000E 01	0.441232E 01	0.767899E-02	0.002
8	0.350000E 02	0.542000E 01	0.546040E 01	-0.403967E-01	-0.007
9	0.690000E 02	0.684000E 01	0.676615E 01	0.738506E-01	0.011
10	0.136000E 03	0.836000E 01	0.837467E 01	-0.146704E-01	-0.002

INVERSE OF P MATRIX

0.411607E 01	-0.359485E 00	-0.447366E 01
-0.359485E 00	0.319197E-01	0.384575E 00
-0.447366E 01	0.384575E 00	0.503438E 01

VARIANCE = 0.123331E-01 WEIGHTED VARIANCE = 0.123331E-01

PARAM 1 = 0.18822489E 01 STANDARD ERROR = 0.22531E 00
PARAM 2 = 0.30772942E 00 STANDARD ERROR = 0.19841E-01
PARAM 3 = -0.16084260E 00 STANDARD ERROR = 0.24918E 00
ITERATIONS = 6

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	Massachusetts Institute of Technology: Research Assistant to Dr. Arthur McCaffrey, Spring and Summer 1966.
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